

# PATENT APPLICATION

## APPARATUS AND METHOD FOR CONTAINING EXCESS THERMAL INTERFACE MATERIAL

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# APPARATUS AND METHOD FOR CONTAINING EXCESS THERMAL INTERFACE MATERIAL

*by Inventor*

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## **Background of the Invention**

### **Field of the Invention**

The present invention relates to semiconductor manufacturing technology generally, and more particularly, to containing thermal interface material in heat spreader technology for heat dissipation in a semiconductor package.

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### **Description of the Related Art**

Semiconductor technology may be characterized as a quest to place more transistors on less space to achieve greater speed and performance. As integrated circuits and other semiconductor devices become faster, operating frequencies (*i.e.* clock speed in a microprocessor) also increase. At the same time, engineers and developers also strive to construct semiconductor devices that are more compact, therefore the distances between the conductive lines within the semiconductor device are being decreased accordingly.

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As the density of conductive lines in and the clock speed of circuits increase, the amount of heat generated by the device also increases. Unfortunately, device reliability and performance decrease as the amount of heat increases, whether the heat is generated by the device or from other sources. In addition, semiconductor devices are prone to overheating, which is a point of heat tolerance past which, the device will fail and be unable to operate. Therefore, it is critical to have an efficient heat-removal system associated with integrated circuits. One conventional method to remove heat from a chip package is by using a heat spreader, which may also be used in combination with a second level solution.

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Figure 1 illustrates a conventional chip package 10. Chip package 10 includes a chip die 12 supported by a substrate 14. Substrate 14 is also able to support other various circuit

components, such as capacitors 16. Chip package 10 also includes a heat spreader 18, which is coupled to chip die 12 through a thermal conductor known as a thermal interface material (TIM) layer 20. Heat spreader 18 is also attached to substrate 14 using a sealant 22. A second level solution, such as a heat sink (not illustrated) may also be coupled to heat spreader 18 to absorb heat generated from the circuitry in chip package 10.

Heat spreaders are becoming more and more important in semiconductor technology, particularly because semiconductor devices, including chip package 10, continue to become more compact. As devices continue to decrease in size, the performance of heat spreaders must continue to improve. Therefore, it is important to evenly distribute heat generated by chip package 10, which is the function of heat spreader 18, which typically comprises a ceramic material or a metal, such as aluminum or copper. Heat spreader 18 is coupled to chip die 12 and capacitors 16 through TIM layer 20.

Examples of TIM include polymer gel, grease or polymer/solder hybrid containing metal particles to improve heat conduction. Using a or solder in TIM layer 20 results in improved thermal conductivity, which is important for future microprocessors, which will generate even more heat. However, a disadvantage of using solder or a stiffer polymer in the TIM occurs in the process of forming the TIM itself. Unlike normal polymeric TIM, which is formed by curing and gelling, a solder or polymer/solder preform must be heated to form a liquid so that it may be evenly distributed on the bottom surface of heat spreader 18. However, during the time that the preform is in liquid form, it is difficult to control the flow of the thermal interface material.

Figure 2 is a x-ray diagram illustrating a solder TIM layer 20 being formed in chip package 10. As described above, the preform solder is heated to form a liquid. After being heated, the liquid preform reflows to wet chip die 12 and cools to form TIM layer 20. Unfortunately, because the solder TIM assumes liquid form during the process and because the reflow is difficult to control, the liquid solder is likely to flow onto and build up on substrate 14 (illustrated in Figure 1).

Often the reflow of liquid solder will enter areas reserved for other sensitive circuit components in chip package 10, such as capacitors 16. When the liquid TIM comes into contact with circuit components supported by substrate 14, the capacitors 16 will likely short circuit, leading to failure of chip package 10. In addition, the build up of excess TIM on substrate 14 may cause stress concentrations. The excess TIM may expand and contract, initiating cracks in substrate 14 on either the die to solder interface or the heat spreader to solder interface, resulting in a reduction in thermal performance.

In view of the foregoing, what is needed is a method and apparatus providing for the rapid dissipation of heat through a thermal interface material to a heat spreader. It is also desirable to provide for beading TIM evenly on a substrate surface and to prevent excess TIM from flowing into contact with sensitive parts of a chip package.

## **Brief Description of the Drawings**

The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements.

5           Figure 1 illustrates a conventional chip package.

Figure 2 is a x-ray diagram illustrating a TIM layer being formed in the chip package.

Figure 3 illustrates a cross-sectional view of a semiconductor package in accordance with one embodiment of the present invention.

10           Figure 4 illustrates a bottom surface of the integrated heat spreader in accordance with one embodiment of the present invention.

Figures 5A-5C are cross sectional views of a number of integrated heat spreaders in accordance with several embodiments of the present invention.

Figure 6 is a flowchart of a method for containing excess solder TIM in a semiconductor package.

## **Detailed Description**

A method and apparatus to contain excess thermal interface material for a semiconductor chip package is provided. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be understood, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to unnecessarily obscure the present invention.

Figure 3 illustrates a cross-sectional view of a semiconductor package 30 in accordance with one embodiment of the present invention. Semiconductor package 30 includes a semiconductor device 32, such as a chip die, supported by a substrate 34. Semiconductor device 32 is typically both mechanically and electrically coupled to the top surface of substrate 34. Substrate 34 also includes a wiring layer that electrically couples device 32 to a set of pins or balls 36 (*i.e.* in a pin grid array (PGA) or ball grid array (BGA)) located along the bottom surface of substrate 34. Examples of substrate 34 include a printed circuit board (PCB), silicon or ceramic.

An integrated heat spreader (IHS) 38 is attached to substrate 34 with a sealant 40, which may include silicone or other proprietary sealant material. IHS 38 is preferably formed from a carbon/carbon, carbon/metal matrix fiber reinforced composite, or metal (*i.e.* copper or aluminum coated with electrolytic nickel with gold above the die). The surface area of IHS 38 is preferably about 31 mm<sup>2</sup> to about 38 mm<sup>2</sup>. IHS 38 may also be coupled to a second level solution, such as a heat sink (not illustrated). Sealant 40 surrounds device 32 and fills the gap between substrate 34 and IHS 38, forming a cavity-encapsulating device 32. The use of sealant 40 provides for a flexible bond between substrate 34 and IHS 38. Sealant 40 is preferably about 0.5 mils to about 9.0 mils in thickness (1 mil = 25 microns).

IHS 38 is thermally coupled to semiconductor device 32 through a heat transfer medium known as a thermal interface material (TIM) layer 42. A direct connection between IHS 38 and semiconductor device 32 would result in poor contact and poor thermal

conductivity. Therefore, TIM layer 42, which is malleable, is necessary to fill in the spatial voids and gaps between IHS 38 and device 32, providing good contact to both IHS 38 and device 32. A highly thermally conductive medium is thus provided as heat is transferred from device 32 to IHS 38 through TIM layer 42.

5           Examples of preferred materials that may be used to form TIM 42 include thermal grease or thermal gel, solder, polymer/solder or polymer. In particular, it has been discovered that TIM comprising solder (such as Indium) is optimal for thermal conductivity. During Tres performance testing with heater tracers, using solder TIM resulted in improved thermal removal. Assuming that TIM layer 42 comprises solder, it is therefore able to  
10       provide a superior heat transfer medium for and accommodate a microprocessor road map trending towards increased power consumption and power density.

Figure 4 illustrates a bottom surface of IHS 38 in accordance with one embodiment of the present invention. The surface area of IHS 38 is preferably about 31 mm<sup>2</sup> to about 38 mm<sup>2</sup>. IHS 38 is preferably formed from copper, which has the best conductivity among IHS  
15       materials. IHS 38 includes a lip 44, an outer area 46, a trough or a channel 48, and a central area 50 (also referred to as a die area due to location semiconductor device 32). Lip 44 is preferably raised relative to a bottom surface of outer area 46 and die area 50. As shown in Figures 3 and 4, lip 44 is raised to couple to substrate 34 and encapsulate semiconductor device 32. Die area 50 is preferably large enough to provide a uniform IHS surface to  
20       receive heat from semiconductor device 32 through TIM layer 42. Die area 50 and other bottom surfaces of IHS 38 also preferably have a flatness of about 35 microns.

As described above with regard to dissipating heat from semiconductor device 32, the bottom surface of IHS 38 is thermally coupled to solder TIM layer 42, which functions as a heat transfer medium. Unlike a polymeric TIM, a TIM comprising solder starts as a preform,  
25       which is a piece of solder material, preferably having the dimensions of a square (i.e. 0.5 inches by 0.5 inches), preferably having a thickness of about 12 mils. The solder preform must be melted and cooled to solidify into a TIM layer 42 that completely wets device 32. The reflow process is necessary to eliminate bubbles and voids in solder TIM layer 42.

During this process, excess liquid solder may flow onto the substrate 34 causing a multitude of problems, including the shorting out of circuit components supported by substrate 34 and initiating cracks in substrate 34. Reducing the size of the solder preform to control this excess flow is not an acceptable solution because there would not be enough liquid solder to completely wet semiconductor device 32 and provide adequate thermal conductivity to IHS 38.

To resolve the overflow of liquid solder TIM, channel 48 is preferably recessed relative to the bottom surfaces of outer area 46 and die area 50 forming a trough or a cavity. Channel 48 is also preferably plated with a wetting layer of high surface energy material, such as gold over electrolytic nickel. The gold provides for superior wetting of channel 48 by attracting excess Indium solder that would otherwise spill onto substrate 34. Accordingly, channel 48 provides for containment of excess solder and prevents the solder from cracking substrate 34 or shorting out circuitry (typically capacitors) supported by substrate 34. Other high surface energy material such as silver may also be used to attract the excess solder in different areas of IHS 38, including die area 50.

It is important to note that in another embodiment of the present invention, semiconductor package 30 described in Figure 3 may be flipped over so that substrate 34 is at the top of package 30 and IHS 38 is at the bottom. In the flipped package, the illustration of IHS 38 in Figure 4 would then represent the top surface of the IHS instead of the bottom surface. Although it may be useful to have a wetting layer of high surface energy material on the top surface of an IHS in a flipped semiconductor package, it may also be possible to eliminate the wetting layer. If the wetting layer is not used, existing gravity could be used to draw excess TIM to the channel of the top surface of the IHS.

In yet another embodiment of the present invention, TIM comprising solder or a polymer/solder hybrid may be used to conduct heat between a IHS and a second level solution such as heat sink. The same principles for reflow could be applied to TIM disposed between an IHS and a heat pipe in mobile packages. The present invention may also be adopted to improve thermal conductivity between an IHS and a heat sink by creating a channel for overflow of excess TIM on the surface of the IHS, which faces the heat sink. As



with previously described embodiments of the present invention, the channels may be stamped into the IHS to produce a low cost method of manufacturing the IHS. As is well known to the person of skill in the art, there are many methods that may be used to stamp features onto an IHS.

5            Figures 5A-5C are cross sectional views of integrated heat spreaders 38a-c in accordance with several embodiments of the present invention. Each IHS 38a-c includes a different embodiment of the present invention, as indicated by channels 48a-c. As illustrated, an IHS channel may be square, rectangular, or even take the form of a semi-circle. Channels have a preferable depth of between about 0.5 mils to about 5.0 mils deep.  
10    In addition, channels are also preferably between about 0.5 mils to about 5.0 mils wide, although the width is only limited by the width of the IHS. The bond line thickness (BLT) of IHSs 38a-c is preferably about 8 to about 15 mils thick.

            Figure 6 is a flowchart of a method 52 for containing excess solder TIM in a semiconductor package. Method 52 begins at a block 54 where a semiconductor device is  
15    provided. The semiconductor device is preferably attached to and supported by a surface of a substrate. Depending on the assembly of the semiconductor package, the surface may be on the top or the bottom of the substrate. A heat spreader, preferably comprising copper is provided in a block 56. The heat spreader preferably includes a surface having a die area and a channel. Again, the heat spreader surface may be on the top or bottom of the heat spreader  
20    depending on the surface of the substrate used to support the semiconductor package. The die area is preferably to be placed directly above the semiconductor device (chip die) and the channel is preferably recessed relative to the die area.

            In block 58, a TIM layer is formed and then disposed between the semiconductor device and the heat spreader. The TIM layer preferably comprises solder, such as Indium, or  
25    a polymer/solder hybrid material. The TIM layer is preferably formed by melting the solder preform. An electric flux is preferably placed on both the semiconductor device and the heat spreader to improve wettability. In addition, the heat spreader, including the channel, is preferably plated with gold and electrolytic nickel, which attracts the solder TIM. A portion of the TIM layer is therefore disposed in the channel in a block 60 after melting, reflow, and

solidification. A force from a clip from about 4 pounds per square foot to about 22 pounds per square foot is preferably applied to the IHS to aid the deposition of the TIM layer.

Other embodiments of the invention will be appreciated by those skilled in the art from consideration of the specification and practice of the invention. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention. The embodiments and preferred features described above should be considered exemplary, with the invention being defined by the appended claims.